Python 3 Metaprogramming

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Requirements

- Python 3.3 or more recent
- Don't even attempt on any earlier version
- Support files:

http://www.dabeaz.com/py3meta

Welcome!

- An advanced tutorial on two topics
  - Python 3
  - Metaprogramming
- Honestly, can you have too much of either?
- No!

Metaprogramming

- In a nutshell: code that manipulates code
- Common examples:
  - Decorators
  - Metaclasses
  - Descriptors
- Essentially, it's doing things with code

Why Would You Care?

- Extensively used in frameworks and libraries
- Better understanding of how Python works
- It's fun
- It solves a practical problem

DRY

DRY

Don't Repeat Yourself

DRY

Don't Repeat Yourself

Don't Repeat Yourself

Don't Repeat Yourself

- Highly repetitive code sucks
- Tedious to write
- Hard to read
- Difficult to modify

This Tutorial

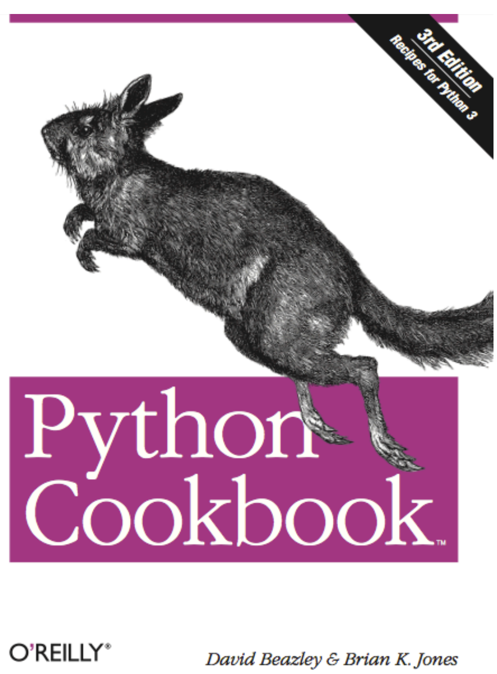
- A modern journey of metaprogramming
- Highlight unique aspects of Python 3
- Explode your brain

Target Audience

- Framework/library builders
- Anyone who wants to know how things work
- Programmers wishing to increase "job security"

Reading

- Tutorial loosely based on content in "Python Cookbook, 3rd Ed."
- Published May, 2013
- You'll find even more information in the book



Preliminaries

Basic Building Blocks

```
statement1
statement2
statement3
...
```

Code

```
def func(args):
    statement1
    statement2
    statement3
    ...
```

```
class A:
    def method1(self, args):
        statement1
        statement2
    def method2(self, args):
        statement1
        statement2
        ...
```

Statements

```
statement1
statement2
statement3
...
```

- Perform the actual work of your program
- Always execute in two scopes
  - globals - Module dictionary
  - locals - Enclosing function (if any)
- exec(*statements* [, *globals* [, *locals*]])

Functions

```
def func(x, y, z):
    statement1
    statement2
    statement3
    ...
```

- The fundamental unit of code in most programs
  - Module-level functions
  - Methods of classes

Calling Conventions

```
def func(x, y, z):
    statement1
    statement2
    statement3
    ...
```

- Positional arguments

```
func(1, 2, 3)
```

- Keyword arguments

```
func(x=1, z=3, y=2)
```


Default Arguments

```
def func(x, debug=False, names=None):
    if names is None:
        names = []
    ...

func(1)
func(1, names=['x', 'y'])
```

- Default values set at <u>definition time</u>
- Only use immutable values (e.g., None)

*args and **kwargs

```
def func(*args, **kwargs):
    # args is tuple of position args
    # kwargs is dict of keyword args
    ...
```

```
func(1, 2, x=3, y=4, z=5)

args = (1, 2)

kwargs = {
    'x': 3,
    'y': 4,
    'z': 5
}
```


*args and **kwargs

```
args = (1, 2)

kwargs = {
    'x': 3,
    'y': 4,
    'z': 5
}

func(*args, **kwargs)
```

same as

```
func(1, 2, x=3, y=4, z=5)
```

Keyword-Only Args

```
def recv(maxsize, *, block=True):
    ...

def sum(*args, initial=0):
    ...
```

- Named arguments appearing after '*' can only be passed by keyword

```
recv(8192, block=False)        # Ok
recv(8192, False)              # Error
```


Closures

- You can make and return functions

```
def make_adder(x, y):
    def add():
        return x + y
    return add
```

- Local variables are captured

```
>>> a = make_adder(2, 3)
>>> b = make_adder(10, 20)
>>> a()
5
>>> b()
30
>>>
```

Classes

```
class Spam:
    a = 1
    def __init__(self, b):
        self.b = b
    def imethod(self):
        pass
```

```
>>> Spam.a          # Class variable
1
>>> s = Spam(2)
>>> s.b             # Instance variable
2
>>> s.imethod()     # Instance method
>>>
```


Different Method Types

<u>Usage</u>

```
class Spam:
    def imethod(self):                    s = Spam()
        pass                              s.imethod()

    @classmethod
    def cmethod(cls):                     Spam.cmethod()
        pass

    @staticmethod
    def smethod():                        Spam.smethod()
        pass
```

Special Methods

```
class Array:
    def __getitem__(self, index):
        ...
    def __setitem__(self, index, value):
        ...
    def __delitem__(self, index):
        ...
    def __contains__(self, item):
        ...
```

- Almost everything can be customized

Inheritance

```
class Base:
    def spam(self):
        ...

class Foo(Base):
    def spam(self):
        ...
        # Call method in base class
        r = super().spam()
```

Dictionaries

- Objects are layered on dictionaries

```
class Spam:
    def __init__(self, x, y):
        self.x = x
        self.y = y
    def foo(self):
        pass
```

- Example:

```
>>> s = Spam(2,3)
>>> s.__dict__
{'y': 3, 'x': 2}
>>> Spam.__dict__['foo']
<function Spam.foo at 0x10069fc20>
>>>
```


Metaprogramming Basics

"I love the smell of debugging in the morning."

Problem: Debugging

- Will illustrate basics with a simple problem
- Debugging
- Not the only application, but simple enough to fit on slides

Debugging with Print

- A function

```
def add(x, y):
    return x + y
```

- A function with debugging

```
def add(x, y):
    print('add')
    return x + y
```

- The one and only true way to debug...

Many Functions w/ Debug

```
def add(x, y):
    print('add')
    return x + y

def sub(x, y):
    print('sub')
    return x - y

def mul(x, y):
    print('mul')
    return x * y

def div(x, y):
    print('div')
    return x / y
```


Many Functions w/ Debug

```
def add(x, y):
    print('add')
    return x + y

def sub(x, y):
    print('sub')
    return x - y

def mul(x, y):
    print('mul')
    return x * y

def div(x, y):
    print('div')
    return x / y
```

Bleah!

Decorators

- A decorator is a function that creates a wrapper around another function
- The wrapper is a new function that works exactly like the original function (same arguments, same return value) except that some kind of extra processing is carried out

A Debugging Decorator

```
from functools import wraps

def debug(func):
    msg = func.__qualname__
    @wraps(func)
    def wrapper(*args, **kwargs):
        print(msg)
        return func(*args, **kwargs)
    return wrapper
```

- Application (wrapping)

```
func = debug(func)
```

A Debugging Decorator

```
from functools import wraps

def debug(func):
    msg = func.__qualname__
    @wraps(func)
    def wrapper(*args, **kwargs):
        print(msg)
        return func(*args, **kwargs)
    return wrapper
```

A decorator creates a "wrapper" function

A Debugging Decorator

```
from functools import wraps

def debug(func):
    msg = func.__qualname__
    @wraps(func)
    def wrapper(*args, **kwargs):
        print(msg)
        return func(*args, **kwargs)
    return wrapper
```

A decorator creates a "wrapper" function

Around a function that you provide

Function Metadata

```
from functools import wraps

def debug(func):
    msg = func.__qualname__
    @wraps(func)
    def wrapper(*args, **kwargs):
        print(msg)
        return func(*args, **kwargs)
    return wrapper
```

- @wraps copies metadata
  - Name and doc string
  - Function attributes

The Metadata Problem

- If you don't use @wraps, weird things happen

```
def add(x,y):
    "Adds x and y"
    return x+y
add = debug(add)

>>> add.__qualname__
'wrapper'
>>> add.__doc__
>>> help(add)
Help on function wrapper in module
__main__:

wrapper(*args, **kwargs)
>>>
```

Decorator Syntax

- The definition of a function and wrapping almost always occur together

```
def add(x,y):
    return x+y
add = debug(add)
```

- @decorator syntax performs the same steps

```
@debug
def add(x,y):
    return x+y
```


Example Use

```
@debug
def add(x, y):
    return x + y

@debug
def sub(x, y):
    return x - y

@debug
def mul(x, y):
    return x * y

@debug
def div(x, y):
    return x / y
```

Example Use

```
@debug
def add(x, y):
    return x + y

@debug
def sub(x, y):
    return x - y

@debug
def mul(x, y):
    return x * y

@debug
def div(x, y):
    return x / y
```

Each function is decorated, but there are no other implementation details

Big Picture

- Debugging code is isolated to single location
- This makes it easy to change (or to disable)
- User of a decorator doesn't worry about it
- That's really the whole idea

Variation: Logging

```
from functools import wraps
import logging

def debug(func):
    log = logging.getLogger(func.__module__)
    msg = func.__qualname__
    @wraps(func)
    def wrapper(*args, **kwargs):
        log.debug(msg)
        return func(*args, **kwargs)
    return wrapper
```


Variation: Optional Disable

```
from functools import wraps
import os

def debug(func):
    if 'DEBUG' not in os.environ:
        return func
    msg = func.__qualname__
    @wraps(func)
    def wrapper(*args, **kwargs):
        print(msg)
        return func(*args, **kwargs)
    return wrapper
```

- Key idea: Can change decorator independently of code that uses it

Debugging with Print

- A function with debugging

```
def add(x, y):
    print('add')
    return x + y
```

- Everyone knows you really need a prefix

```
def add(x, y):
    print('***add')
    return x + y
```

- You know, for grepping...

Decorators with Args

- Calling convention

```
@decorator(args)
def func():
    pass
```

- Evaluates as

```
func = decorator(args)(func)
```

- It's a little weird--two levels of calls

Decorators with Args

```
from functools import wraps

def debug(prefix=''):
    def decorate(func):
        msg = prefix + func.__qualname__
        @wraps(func)
        def wrapper(*args, **kwargs):
            print(msg)
            return func(*args, **kwargs)
        return wrapper
    return decorate
```

- Usage

```
@debug(prefix='***')
def add(x,y):
    return x+y
```


Decorators with Args

```
from functools import wraps

def debug(prefix=''):
    def decorate(func):
        msg = prefix + func.__qualname__
        @wraps(func)
        def wrapper(*args, **kwargs):
            print(msg)
            return func(*args, **kwargs)
        return wrapper
    return decorate
```

Outer function defines variables for use in regular decorator

Normal decorator function

A Reformulation

```
from functools import wraps, partial

def debug(func=None, *, prefix=''):
    if func is None:
        return partial(debug, prefix=prefix)

    msg = prefix + func.__qualname__
    @wraps(func)
    def wrapper(*args, **kwargs):
        print(msg)
        return func(*args, **kwargs)
    return wrapper
```

- A test of your function calling skills...

Usage

- Use as a simple decorator

```
@debug
def add(x, y):
    return x + y
```

- Or as a decorator with optional configuration

```
@debug(prefix='***')
def add(x, y):
    return x + y
```

Debug All Of This

- Debug all of the methods of a class

```
class Spam:
    @debug
    def grok(self):
        pass
    @debug
    def bar(self):
        pass
    @debug
    def foo(self):
        pass
```

- Can you decorate all methods at once?

Class Decorator

```
def debugmethods(cls):
    for name, val in vars(cls).items():
        if callable(val):
            setattr(cls, name, debug(val))
    return cls
```

- Idea:
  - Walk through class dictionary
  - Identify callables (e.g., methods)
  - Wrap with a decorator

Example Use

```
@debugmethods
class Spam:
    def grok(self):
        pass
    def bar(self):
        pass
    def foo(self):
        pass
```

- One decorator application
- Covers all definitions within the class
- It even mostly works...

Limitations

```
@debugmethods
class BrokenSpam:
    @classmethod
    def grok(cls):     # Not wrapped
        pass
    @staticmethod
    def bar():         # Not wrapped
        pass
```

- Only instance methods get wrapped
- Why? An exercise for the reader...

Variation: Debug Access

```
def debugattr(cls):
    orig_getattribute = cls.__getattribute__

    def __getattribute__(self, name):
        print('Get:', name)
        return orig_getattribute(self, name)
    cls.__getattribute__ = __getattribute__

    return cls
```

- Rewriting part of the class itself

Example

```
@debugattr
class Point:
    def __init__(self, x, y):
        self.x = x
        self.y = y

>>> p = Point(2, 3)
>>> p.x
Get: x
2
>>> p.y
Get: y
3
>>>
```

Debug All The Classes

```
@debugmethods
class Base:
    ...

@debugmethods
class Spam(Base):
    ...

@debugmethods
class Grok(Spam):
    ...

@debugmethods
class Mondo(Grok):
    ...
```

- Many classes with debugging
- Didn't we just solve this?
- Bleah!!

Solution: A Metaclass

```
class debugmeta(type):
    def __new__(cls, clsname, bases, clsdict):
        clsobj = super().__new__(cls, clsname,
                                 bases, clsdict)
        clsobj = debugmethods(clsobj)
        return clsobj
```

- Usage

```
class Base(metaclass=debugmeta):
    ...

class Spam(Base):
    ...
```

Solution: A Metaclass

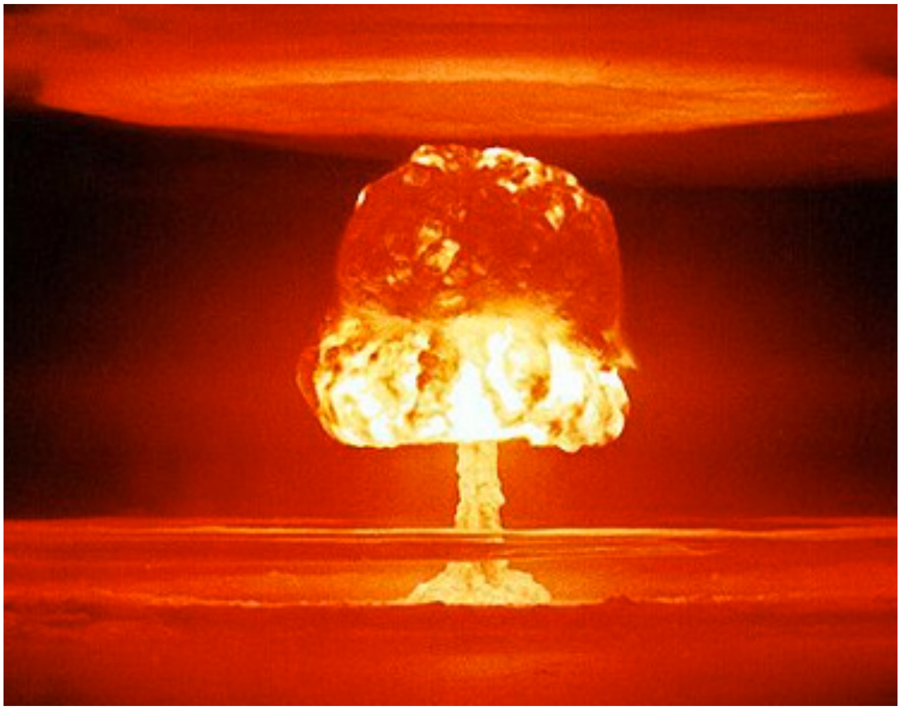
```
class debugmeta(type):
    def __new__(cls, clsname, bases, clsdict):
        clsobj = super().__new__(cls, clsname,
                                 bases, clsdict)
        clsobj = debugmethods(clsobj)
        return clsobj
```

- Idea
  - Class gets created normally

Solution: A Metaclass

```
class debugmeta(type):
    def __new__(cls, clsname, bases, clsdict):
        clsobj = super().__new__(cls, clsname,
                                 bases, clsdict)
        clsobj = debugmethods(clsobj)
        return clsobj
```

- Idea
  - Class gets created normally
  - Immediately wrapped by class decorator



Types

- All values in Python have a type
- Example:

```
>>> x = 42
>>> type(x)
<type 'int'>
>>> s = "Hello"
>>> type(s)
<type 'str'>
>>> items = [1,2,3]
>>> type(items)
<type 'list'>
>>>
```

Types and Classes

- Classes define new types

```
class Spam:
    pass

>>> s = Spam()
>>> type(s)
<class '__main__.Spam'>
>>>
```

- The class is the type of instances created
- The class is a callable that creates instances

Types of Classes

- Classes are instances of types

```
>>> type(int)
<class 'int'>
>>> type(list)
<class 'list'>
>>> type(Spam)
<class '__main__.Spam'>
>>> isinstance(Spam, type)
True
>>>
```

- This requires some thought, but it should make some sense (classes are types)

Creating Types

- Types are their own class (builtin)

```
class type:
    ...

>>> type
<class 'type'>
>>>
```

- This class creates new "type" objects
- Used when defining classes

Classes Deconstructed

- Consider a class:

```
class Spam(Base):
    def __init__(self, name):
        self.name = name
    def bar(self):
        print "I'm Spam.bar"
```

- What are its components?
  - Name ("Spam")
  - Base classes (Base,)
  - Functions (__init__,bar)

Class Definition Process

- What happens during class definition?

```
class Spam(Base):
    def __init__(self, name):
        self.name = name
    def bar(self):
        print "I'm Spam.bar"
```

- Step1: Body of class is isolated

```
body = '''
   def __init__(self, name):
        self.name = name
   def bar(self):
        print "I'm Spam.bar"
'''
```


Class Definition

- Step 2: The class dictionary is created

```
clsdict = type.__prepare__('Spam', (Base,))
```

- This dictionary serves as local namespace for statements in the class body
- By default, it's a simple dictionary (more later)

Class Definition

- Step 3: Body is executed in returned dict

```
exec(body, globals(), clsdict)
```

- Afterwards, clsdict is populated

```
>>> clsdict
{'__init__': <function __init__ at 0x4da10>,
 'bar': <function bar at 0x4dd70>}
>>>
```


Class Definition

- Step 4: Class is constructed from its name, base classes, and the dictionary

```
>>> Spam = type('Spam', (Base,), clsdict)
>>> Spam
<class '__main__.Spam'>
>>> s = Spam('Guido')
>>> s.bar()
I'm Spam.bar
>>>
```

Changing the Metaclass

- metaclass keyword argument
- Sets the class used for creating the type

```
class Spam(metaclass=type):
    def __init__(self,name):
        self.name = name
    def bar(self):
        print "I'm Spam.bar"
```

- By default, it's set to 'type', but you can change it to something else

Defining a New Metaclass

- You typically inherit from type and redefine __new__ or __init__

```
class mytype(type):
    def __new__(cls, name, bases, clsdict):
        clsobj = super().__new__(cls,
                                 name,
                                 bases,
                                 clsdict)
        return clsobj
```

- To use

```
class Spam(metaclass=mytype):
    ...
```

Using a Metaclass

- Metaclasses get information about class definitions at the time of definition
    - Can inspect this data
    - Can modify this data
- Essentially, similar to a class decorator
- Question: Why would you use one?

Inheritance

- Metaclasses propagate down hierarchies

```
class Base(metaclass=mytype):
    ...

class Spam(Base):      # metaclass=mytype
    ...

class Grok(Spam):      # metaclass=mytype
    ...
```

- Think of it as a genetic mutation

Solution: Reprise

```
class debugmeta(type):
    def __new__(cls, clsname, bases, clsdict):
        clsobj = super().__new__(cls, clsname,
                                 bases, clsdict)
        clsobj = debugmethods(clsobj)
        return clsobj
```

- Idea
  - Class gets created normally
  - Immediately wrapped by class decorator

Debug The Universe

```
class Base(metaclass=debugmeta):
    ...

class Spam(Base):
    ...

class Grok(Spam):
    ...

class Mondo(Grok):
    ...
```

- Debugging gets applied across entire hierarchy
- Implicitly applied in subclasses

Big Picture

- It's mostly about wrapping/rewriting
  - Decorators : Functions
  - Class Decorators: Classes
  - Metaclasses : Class hierarchies
- You have the power to change things

Interlude

Journey So Far

- Have seen "classic" metaprogramming
- Already widely used in Python 2
- Only a few Python 3 specific changes

Journey to Come

- Let's build something more advanced
- Using techniques discussed
- And more...

Problem : Structures

```
class Stock:
    def __init__(self, name, shares, price):
        self.name = name
        self.shares = shares
        self.price = price

class Point:
    def __init__(self, x, y):
        self.x = x
        self.y = y

class Host:
    def __init__(self, address, port):
        self.address = address
        self.port = port
```


Problem : Structures

```
class Stock:
    def __init__(self, name, shares, price):
        self.name = name
        self.shares = shares
        self.price = price

class Point:
    def __init__(self, x, y):
        self.x = x
        self.y = y

class Host:
    def __init__(self, address, port):
        self.address = address
        self.port = port
```

Why must I keep writing these boilerplate init methods?

A Solution : Inheritance

```
class Structure:
    _fields = []
    def __init__(self, *args):
        if len(args) != self._fields:
            raise TypeError('Wrong # args')
        for name, val in zip(self._fields, args):
            setattr(self, name, val)

class Stock(Structure):
    _fields = ['name', 'shares', 'price']

class Point(Structure):
    _fields = ['x', 'y']

class Host(Structure):
    _fields = ['address', 'port']
```

A generalized __init__()

Usage

```
>>> s = Stock('ACME', 50, 123.45)
>>> s.name
'ACME'
>>> s.shares
50
>>> s.price
123.45

>>> p = Point(4, 5)
>>> p.x
4
>>> p.y
5
>>>
```

Some Issues

- No support for keyword args

```
>>> s = Stock('ACME', price=123.45, shares=50)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: __init__() got an unexpected keyword
argument 'shares'
>>>
```

- Missing calling signatures

```
>>> import inspect
>>> print(inspect.signature(Stock))
(*args)
>>>
```


Put a Signature on It

New Approach: Signatures

- Build a function signature object

```
from inspect import Parameter, Signature

fields = ['name', 'shares', 'price']
parms = [ Parameter(name,
                    Parameter.POSITIONAL_OR_KEYWORD)
          for name in fields]
sig = Signature(parms)
```

- Signatures are more than just metadata

Signature Binding

- Argument binding

```
def func(*args, **kwargs):
    bound_args = sig.bind(*args, **kwargs)
    for name, val in bound_args.arguments.items():
        print(name, '=', val)
```

- sig.bind() binds positional/keyword args to signature
- .arguments is an OrderedDict of passed values

Signature Binding

- Example use:

```
>>> func('ACME', 50, 91.1)
name = ACME
shares = 50
price = 91.1

>>> func('ACME', price=91.1, shares=50)
name = ACME
shares = 50
price = 91.1
```

- Notice: both positional/keyword args work

Signature Binding

- Error handling

```
>>> func('ACME', 50)
Traceback (most recent call last):
...
TypeError: 'price' parameter lacking default value

>>> func('ACME', 50, 91.1, 92.3)
Traceback (most recent call last):
...
TypeError: too many positional arguments
>>>
```

- Binding: it just "works"

Solution w/Signatures

```
from inspect import Parameter, Signature

def make_signature(names):
    return Signature(
           Parameter(name,
                 Parameter.POSITIONAL_OR_KEYWORD)
           for name in names)

class Structure:
    __signature__ = make_signature([])
    def __init__(self, *args, **kwargs):
        bound = self.__signature__.bind(
                                *args, **kwargs)
        for name, val in bound.arguments.items():
            setattr(self, name, val)
```


Solution w/Signatures

```
class Stock(Structure):
    __signature__ = make_signature(
                      ['name','shares','price'])

class Point(Structure):
    __signature__ = make_signature(['x', 'y'])

class Host(Structure):
    __signature__ = make_signature(
                      ['address', 'port'])
```

Solution w/Signatures

```
>>> s = Stock('ACME', shares=50, price=91.1)
>>> s.name
'ACME'
>>> s.shares
50
>>> s.price
91.1
>>> import inspect
>>> print(inspect.signature(Stock))
(name, shares, price)
>>>
```


New Problem

- This is rather annoying

```
class Stock(Structure):
    __signature__ = make_signature(
                      ['name','shares','price'])

class Point(Structure):
    __signature__ = make_signature(['x', 'y'])

class Host(Structure):
    __signature__ = make_signature(
                      ['address', 'port'])
```

- Can't it be simplified in some way?

Solutions

- Ah, a problem involving class definitions
  - Class decorators
  - Metaclasses
- Which seems more appropriate?
- Let's explore both options

Class Decorators

```
def add_signature(*names):
    def decorate(cls):
        cls.__signature__ = make_signature(names)
        return cls
    return decorate
```

- Usage:

```
@add_signature('name','shares','price')
class Stock(Structure):
    pass

@add_signature('x','y')
class Point(Structure):
    pass
```

Metaclass Solution

```
class StructMeta(type):
    def __new__(cls, name, bases, clsdict):
        clsobj = super().__new__(cls, name,
                                 bases, clsdict)
        sig = make_signature(clsobj._fields)
        setattr(clsobj, '__signature__', sig)
        return clsobj

class Structure(metaclass=StructMeta):
    _fields = []
    def __init__(self, *args, **kwargs):
        bound = self.__signature__.bind(
                                *args, **kwargs)
        for name, val in bound.arguments.items():
            setattr(self, name, val)
```


Metaclass Solution

```
class StructMeta(type):
    def __new__(cls, name, bases, clsdict):
        clsobj = super().__new__(cls, name,
                                 bases, clsdict)
        sig = make_signature(clsobj._fields)
        setattr(clsobj, '__signature__', sig)
        return clsobj

                s=StructMeta):

                rgs, **kwargs):
                ignature__.bind(
                                *args, **kwargs)
        for name, val in bound.arguments.items():
            setattr(self, name, val)
```

Read _fields attribute and make a proper signature out of it

Usage

```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']

class Point(Structure):
    _fields = ['x', 'y']

class Host(Structure):
    _fields = ['address', 'port']
```

- It's back to original 'simple' solution
- Signatures are created behind scenes

Considerations

- How much will the Structure class be expanded?
- Example: supporting methods

```
class Structure(metaclass=StructMeta):
    _fields = []
    ...
    def __repr__(self):
        args = ', '.join(repr(getattr(self, name))
                         for name in self._fields)
        return type(self).__name__ + \
               '(' + args + ')'
```

- Is type checking important?

```
isinstance(s, Structure)
```

Advice

- Use a class decorator if the goal is to tweak classes that might be unrelated
- Use a metaclass if you're trying to perform actions in combination with inheritance
- Don't be so quick to dismiss techniques (e.g., '*metaclasses suck so .... blah blah*')
- All of the tools are meant to work together

Owning the Dot

Q: "*Who's in charge here?*"
A: "*In charge? I don't know, man.*"

Problem : Correctness

- Types like a duck, rhymes with ...

```
>>> s = Stock('ACME', 50, 91.1)
>>> s.name = 42
>>> s.shares = 'a heck of a lot'
>>> s.price = (23.45 + 2j)
>>>
```

- Bah, real programmers use Haskell!

Properties

- You can upgrade attributes to have checks

```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']

    @property
    def shares(self):
        return self._shares

    @shares.setter
    def shares(self, value):
        if not isinstance(value, int):
            raise TypeError('expected int')
        if value < 0:
            raise ValueError('Must be >= 0')
        self._shares = value
```

(getter)

(setter)

Properties

- Example use:

```
>>> s = Stock('ACME', 50, 91.1)
>>> s.shares = 'a lot'
Traceback (most recent call last):
...
TypeError: expected int
>>> s.shares = -10
Traceback (most recent call last):
...
ValueError: Must be >= 0
>>> s.shares = 37
>>> s.shares
37
>>>
```


An Issue

- It works, but it quickly gets annoying

```
@property
def shares(self):
    return self._shares

@shares.setter
def shares(self, value):
    if not isinstance(value, int):
        raise TypeError('expected int')
    if value < 0:
        raise ValueError('Must be >= 0')
    self._shares = value
```

- Imagine writing same code for many attributes

A Complexity

- Want to simplify, but how?
- Two kinds of checking are intertwined
- Type checking: int, float, str, etc.
- Validation: >, >=, <, <=, !=, etc.
- Question: How to structure it?

Descriptor Protocol

- Properties are implemented via descriptors

```
class Descriptor:
    def __get__(self, instance, cls):
        ...
    def __set__(self, instance, value):
        ...
    def __delete__(self, instance)
        ...
```

- Customized processing of attribute access

Descriptor Protocol

- Example:

```
class Spam:
    x = Descriptor()
s = Spam()

s.x             # x.__get__(s, Spam)
s.x = value     # x.__set__(s, value)
del s.x         # x.__delete__(s)
```

- Customized handling of a specific attribute

A Basic Descriptor

```
class Descriptor:
    def __init__(self, name=None):
        self.name = name

    def __get__(self, instance, cls):
        if instance is None:
            return self
        else:
            return instance.__dict__[self.name]

    def __set__(self, instance, value):
        instance.__dict__[self.name] = value

    def __delete__(self, instance):
        del instance.__dict__[self.name]
```

A Basic Descriptor

```
class Descriptor:
    def __init__(self, name=None):
        self.name = name

    def __get__(self, 
        if instance is
            return sel
        else:
            return ins                  ame]

    def __set__(self, instance, value):
        instance.__dict__[self.name] = value

    def __delete__(self, instance):
        del instance.__dict__[self.name]
```

name of attribute being stored. A key in the instance dict.

A Basic Descriptor

```
class Descriptor:
    def __init__(self, name=None):
        self.name = name

    def __get__(self, instance,
        if instance is None:
            return self
        else:
            return instance.__dict__[self.name]

    def __set__(self, instance, value):
        instance.__dict__[self.name] = value

    def __delete__(self, instance):
        del instance.__dict__[self.name]
```

Direct manipulation of the instance dict.

A Simpler Descriptor

```
class Descriptor:
    def __init__(self, name=None):
        self.name = name

    def __set__(self, instance, value):
        instance.__dict__[self.name] = value

    def __delete__(self, instance):
        raise AttributeError("Can't delete")
```

- You don't need __get__() if it merely returns the normal dictionary value

Descriptor Usage

```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']
    name = Descriptor('name')
    shares = Descriptor('shares')
    price = Descriptor('price')
```

- If it works, will capture set/delete operations

```
>>> s = Stock('ACME', 50, 91.1)
>>> s.shares
50
>>> s.shares = 50   # shares.__set__(s, 50)
>>> del s.shares
Traceback (most recent call last):
...
AttributeError: Can't delete
>>>
```

Type Checking

```
class Typed(Descriptor):
    ty = object
    def __set__(self, instance, value):
        if not isinstance(value, self.ty):
            raise TypeError('Expected %s' % self.ty)
        super().__set__(instance, value)
```

- Specialization

```
class Integer(Typed):
    ty = int
class Float(Typed):
    ty = float
class String(Typed):
    ty = str
```


Usage

```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']
    name = String('name')
    shares = Integer('shares')
    price = Float('price')
```

- Example:

```
>>> s = Stock('ACME', 50, 91.1)
>>> s.shares = 'a lot'
Traceback (most recent call last):
...
TypeError: Expected <class 'int'>
>>> s.name = 42
Traceback (most recent call last):
...
TypeError: Expected <class 'str'>
>>>
```

Value Checking

```
class Positive(Descriptor):
    def __set__(self, instance, value):
        if value < 0:
            raise ValueError('Expected >= 0')
        super().__set__(instance, value)
```

- Use as a mixin class

```
class PosInteger(Integer, Positive):
    pass

class PosFloat(Float, Positive):
    pass
```


Usage

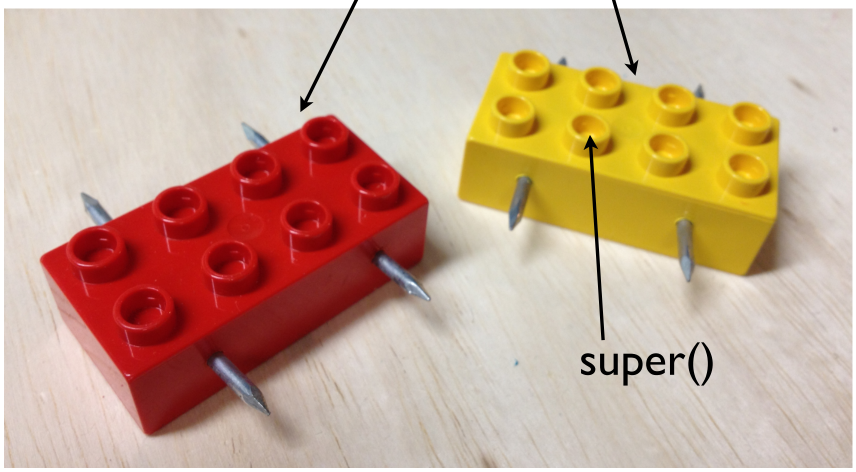
```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']
    name = String('name')
    shares = PosInteger('shares')
    price = PosFloat('price')
```

- Example:

```
>>> s = Stock('ACME', 50, 91.1)
>>> s.shares = -10
Traceback (most recent call last):
...
ValueError: Expected >= 0
>>> s.shares = 'a lot'
Traceback (most recent call last):
...
TypeError: Expected <class 'int'>
>>>
```

Building Blocks!

```
class PosInteger(Integer, Positive):
    pass
```



Understanding the MRO

```
class PosInteger(Integer, Positive):
    pass
```

```
>>> PosInteger.__mro__
(<class 'PosInteger'>,
 <class 'Integer'>,
 <class 'Typed'>,
 <class 'Positive'>,
 <class 'Descriptor'>,
 <class 'object'>)
>>>
```

This chain defines the order in which the value is checked by different __set__() methods

- Base order matters (e.g., int before < 0)

Length Checking

```
class Sized(Descriptor):
    def __init__(self, *args, maxlen, **kwargs):
        self.maxlen = maxlen
        super().__init__(*args, **kwargs)

    def __set__(self, instance, value):
        if len(value) > self.maxlen:
            raise ValueError('Too big')
        super().__set__(instance, value)
```

- Use:

```
class SizedString(String, Sized):
    pass
```


Usage

```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']
    name = SizedString('name', maxlen=8)
    shares = PosInteger('shares')
    price = PosFloat('price')
```

- Example:

```
>>> s = Stock('ACME', 50, 91.1)
>>> s.name = 'ABRACADABRA'
Traceback (most recent call last):
...
ValueError: Too big
>>>
```

Pattern Checking

```
import re
class Regex(Descriptor):
    def __init__(self, *args, pat, **kwargs):
        self.pat = re.compile(pat)
        super().__init__(*args, **kwargs)

    def __set__(self, instance, value):
        if not self.pat.match(value):
            raise ValueError('Invalid string')
        super().__set__(instance, value)
```

- Use:

```
class SizedRegexString(String, Sized, Regex):
    pass
```


Usage

```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']
    name = SizedRegexString('name', maxlen=8,
                            pat='[A-Z]+$')
    shares = PosInteger('shares')
    price = PosFloat('price')
```

- Example:

```
>>> s = Stock('ACME', 50, 91.1)
>>> s.name = 'Head Explodes!'
Traceback (most recent call last):
...
ValueError: Invalid string
>>>
```

Whoa, Whoa, Whoa

- Mixin classes with __init__() functions?

```
class SizedRegexString(String, Sized, Regex):
    pass
```

- Each with own unique signature

```
a = String('name')
b = Sized(maxlen=8)
c = Regex(pat='[A-Z]+$')
```

- This works, how?

Keyword-only Args

```
SizedRegexString('name', maxlen=8, pat='[A-Z]+$')

class Descriptor:
    def __init__(self, name=None):
        ...

class Sized(Descriptor):
    def __init__(self, *args, maxlen, **kwargs):
        ...
        super().__init__(*args, **kwargs)

class Regex(Descriptor):
    def __init__(self, *args, pat, **kwargs):
        ...
        super().__init__(*args, **kwargs)
```

Keyword-only Args

```
SizedRegexString('name', maxlen=8, pat='[A-Z]+$')

class Descriptor:
    def __init__(self, name=None):
        ...

class Sized(Descriptor):
    def __init__(self, *args, maxlen, **kwargs):
        ...
        super().__init__(*args, **kwargs)

class                                t, **kwargs):
    c

                                       **kwargs)
```

Keyword-only argument is isolated and removed from all other passed args

"Awesome, man!"

Annoyance

```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']
    name = SizedRegexString('name', maxlen=8,
                            pat='[A-Z]+$')
    shares = PosInteger('shares')
    price = PosFloat('price')
```

- Still quite a bit of repetition
- Signatures and type checking not unified
- Maybe we can push it further

A New Metaclass

```
from collections import OrderedDict
class StructMeta(type):
   @classmethod
    def __prepare__(cls, name, bases):
        return OrderedDict()

    def __new__(cls, name, bases, clsdict):
        fields = [ key for key, val in clsdict.items()
                   if isinstance(val, Descriptor) ]
        for name in fields:
            clsdict[name].name = name

        clsobj = super().__new__(cls, name, bases,
                                 dict(clsdict))
        sig = make_signature(fields)
        setattr(clsobj, '__signature__', sig)
        return clsobj
```


New Usage

```
class Stock(Structure):
    name = SizedRegexString(maxlen=8,pat='[A-Z]+$')
    shares = PosInteger()
    price = PosFloat()
```

- Oh, that's rather nice...

New Metaclass

```
from collections import OrderedDict
class StructMeta(type):
   @classmethod
    def __prepare__(cls, name, bases):
        return OrderedDict()

    def __new__(cls, name,
        fields = [ key for
                   if isins
        for name in fields:
            clsdict[name].n

        clsobj = super().__

        sig = make_signatur
        setattr(clsobj, '__
        return clsobj
```

__prepare__() creates and returns dictionary to use for execution of the class body.

An OrderedDict will preserve the definition order.

Ordering of Definitions

```
class Stock(Structure):
    name = SizedRegexString(maxlen=8,pat='[A-Z]+$')
    shares = PosInteger()
    price = PosFloat()
```

```
clsdict = OrderedDict(
   ('name', <class 'SizedRegexString'>),
   ('shares', <class 'PosInteger'>),
   ('price', <class 'PosFloat'>)
)
```

Duplicate Definitions

- If inclined, you could do even better
- Make a new kind of dict

```
class NoDupOrderedDict(OrderedDict):
    def __setitem__(self, key, value):
        if key in self:
            raise NameError('%s already defined'
                                 % key)
        super().__setitem__(key, value)
```

- Use in place of OrderedDict

Duplicate Definitions

```
class Stock(Structure):
    name = String()
    shares = PosInteger()
    price = PosFloat()
    shares = PosInteger()


Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<stdin>", line 5, in Stock
  File "./typestruct.py", line 107, in __setitem__
    raise NameError('%s already defined' % key)
NameError: shares already defined
```

- Won't pursue further, but you get the idea

New Metaclass

```
from collections import OrderedDict
class StructMeta(type):
   @classmethod
    def __prepare__(cls, name, bases):
        return OrderedDict()

    def __new__(cls, name, bases, clsdict):
        fields = [ key for key, val in clsdict.items()
                   if isinstance(val, Descriptor) ]
        for name in fields:
            clsdict[name].name = name

                          ew__(cls, name, bases,
                                  dict(clsdict))
                          (fields)
        setattr(clsobj, '__signature__', sig)
        return clsobj
```

Collect Descriptors and set their names

Name Setting

- Old code

```
class Stock(Structure):
    _fields = ['name', 'shares', 'price']
    name = SizedRegexString('name', ...)
    shares = PosInteger('shares')
    price = PosFloat('price')
```

- New Code

```
class Stock(Structure):
    name = SizedRegexString(...)
    shares = PosInteger()
    price = PosFloat()
```

Names are set from dict keys

New Metaclass

```
from collections import OrderedDict
class StructMeta(type):
   @classmethod
    def __prepare__(cls, name, bases):
        return OrderedDict()

    def __new__(cls, name, bases, clsdict):
        fields =                                ems()
                                                  ]
        for name
            clsd

        clsobj = super().__new__(cls, name, bases,
                                 dict(clsdict))
        sig = make_signature(fields)
        setattr(clsobj, '__signature__', sig)
        return clsobj
```

Make the class and signature exactly as before.

New Metaclass

```
from collections import OrderedDict
class StructMeta(type):
   @classmethod
    def __prepare__(cls, name, bases):
        return OrderedDict()

    def __new__(cls, name, bases, clsdict):
        fields = [ key for key, val in clsdict.items()
                                   scriptor) ]

        clsobj = super().__new__(cls, name, bases,
                                 dict(clsdict))
        sig = make_signature(fields)
        setattr(clsobj, '__signature__', sig)
        return clsobj
```

A technicality: Must create a proper dict for class contents

Performance

The Costs

- Option 1 : Simple

```
class Stock:
    def __init__(self, name, shares, price):
        self.name = name
        self.shares = shares
        self.price = price
```

- Option 2 : Meta

```
class Stock(Structure):
    name = SizedRegexString(...)
    shares = PosInteger()
    price = PosFloat()
```

A Few Tests

	Simple	Meta
• Instance creation		
`s = Stock('ACME', 50, 91.1)`	1.07s	91.8s (86x)
• Attribute lookup		
`s.price`	0.08s	0.08s
• Attribute assignment		
`s.price = 10.0`	0.11s	3.40s (31x)
• Attribute assignment		
`s.name = 'ACME'`	0.14s	8.14s (58x)

A Few Tests

	Simple	Meta
• Instance creation		
`s = Stock('ACME', 50, 91.1)`	1.07s	91.8s (86x)
• Attribute lookup		
`s.price`	**0.08s**	**0.08s**
• Attribute assignment		
`s.price = 10.0`	0.11s	3.40s (31x)
• Attribute assignment		
`s.name = 'ACME'`	0.14s	8.14s (58x)

A bright spot

Thoughts

- Several large bottlenecks
  - Signature enforcement
  - Multiple inheritance/super in descriptors
- Can anything be done without a total rewrite?

Code Generation

```
def _make_init(fields):
    code = 'def __init__(self, %s):\n' % \
           ', '.join(fields)
    for name in fields:
        code += '    self.%s = %s\n' % (name, name)
    return code
```

- Example:

```
>>> code = _make_init(['name','shares','price'])
>>> print(code)
def __init__(self, name, shares, price):
   self.name = name
   self.shares = shares
   self.price = price

>>>
```

Code Generation

```
class StructMeta(type):
    ...
    def __new__(cls, name, bases, clsdict):
        fields = [ key for key, val in clsdict.items()
                   if isinstance(val, Descriptor) ]

        for name in fields:
            clsdict[name].name = name

        if fields:
            exec(_make_init(fields),globals(),clsdict)

        clsobj = super().__new__(cls, name, bases,
                                 dict(clsdict))
        setattr(clsobj, '_fields', fields)
        return clsobj
```


Code Generation

```
class StructMeta(type):
    ...
    def __new__(cls, name, bases, clsdict):
        fields = [ key for key, val in clsdict.items()
                   if isinstance(val, Descriptor) ]

        for name in fields:
            clsdict[name].name = name

        if fields:
            exec(_make_init(fields),globals(),clsdict)

        clsobj = super().__new__(cls, name, bases,
                                 dict(clsdict))
        setattr(clsobj, '_fields', fields)
        return clsobj
```

No signature, but set _fields for code that wants it

New Code

```
class Structure(metaclass=StructMeta):
    pass

class Stock(Structure):
    name = SizedRegexString(...)
    shares = PosInteger()
    price = PosFloat()
```

Instance creation:

Simple	1.1s
Old Meta (w/signatures)	91.8s
New Meta (w/exec)	17. 6s

New Thought

```
class Descriptor:
    ...
    def __set__(self, instance, value):
        instance.__dict__[self.name] = value

class Typed(Descriptor):
    def __set__(self, instance, value):
        if not isinstance(value, self.ty):
            raise TypeError('Expected %s' % self.ty)
        super().__set__(instance, value)

class Positive(Descriptor):
    def __set__(self, instance, value):
        if value < 0:
            raise ValueError('Expected >= 0')
        super().__set__(instance, value)
```

Could you merge this code together?

Reformulation

```
class Descriptor(metaclass=DescriptorMeta):
    def __init__(self, name=None):
        self.name = name

    @staticmethod
    def set_code():
        return [
            'instance.__dict__[self.name] = value'
            ]

    def __delete__(self, instance):
        raise AttributeError("Can't delete")
```

- Change __set__ to a method that returns source
- Introduce a new metaclass (later)

Reformulation

```
class Typed(Descriptor):
    ty = object
    @staticmethod
    def set_code():
        return [
          'if not isinstance(value, self.ty):',
          '    raise TypeError("Expected %s"%self.ty)'
            ]

class Positive(Descriptor):
    @staticmethod
    def set_code(self):
        return [
            'if value < 0:',
            '    raise ValueError("Expected >= 0")'
            ]
```

Reformulation

```
class Sized(Descriptor):
    def __init__(self, *args, maxlen, **kwargs):
        self.maxlen = maxlen
        super().__init__(*args, **kwargs)

    @staticmethod
    def set_code():
        return [
            'if len(value) > self.maxlen:',
            '    raise ValueError("Too big")'
        ]
```


Reformulation

```
import re
class RegexPattern(Descriptor):
    def __init__(self, *args, pat, **kwargs):
        self.pat = re.compile(pat)
        super().__init__(*args, **kwargs)

    @staticmethod
    def set_code():
        return [
            'if not self.pat.match(value):',
            '    raise ValueError("Invalid string")'
            ]
```

Generating a Setter

```
def _make_setter(dcls):
    code = 'def __set__(self, instance, value):\n'
    for d in dcls.__mro__:
        if 'set_code' in d.__dict__:
            for line in d.set_code():
                code += '    ' + line + '\n'
    return code
```

- Takes a descriptor class as input
- Walks its MRO and collects output of set_code()
- Concatenate to make a __set__() method

Example Setters

```
>>> print(_make_setter(Descriptor))
def __set__(self, instance, value):
    instance.__dict__[self.name] = value

>>> print(_make_setter(PosInteger))
def __set__(self, instance, value):
    if not isinstance(value, self.ty):
        raise TypeError("Expected %s" % self.ty)
    if value < 0:
        raise ValueError("Expected >= 0")
    instance.__dict__[self.name] = value

>>>
```

Descriptor Metaclass

```
class DescriptorMeta(type):
    def __init__(self, clsname, bases, clsdict):
        if '__set__' not in clsdict:
            code = _make_setter(self)
            exec(code, globals(), clsdict)
            setattr(self, '__set__',
                    clsdict['__set__'])
        else:
            raise TypeError('Define set_code()')

class Descriptor(metaclass=DescriptorMeta):
    ...
```

- For each Descriptor class, create setter code
- exec() and drop result onto created class

Just to be Clear

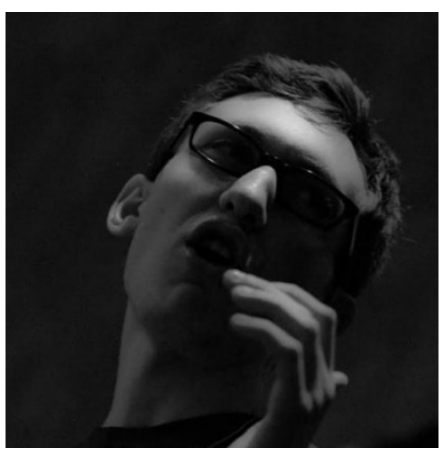
```
class Stock(Structure):
    name = SizedRegexString(...)
    shares = PosInteger()
    price = PosFloat()
```

- User has no idea about this code generation
- They're just using the same code as before
- It's an implementation detail of descriptors

New Performance

	Simple	Meta	Exec
• Instance creation			
`s = Stock('ACME',50,91.1)`	1.07s	91.8s (86x)	**7.19s (6.7x)**
• Attribute lookup			
`s.price`	0.08s	0.08s	**0.08s**
• Attribute assignment			
`s.price = 10.0`	0.11s	3.40s (31x)	**1.11s (10x)**
• Attribute assignment			
`s.name = 'ACME'`	0.14s	8.14s (58x)	**2.95s (21x)**

The Horror! The Horror!



@alex_gaynor

Remaining Problem

- Convincing a manager about all of this

```
class Stock(Structure):
    name = SizedRegexString(maxlen=8, pat='[A-Z]+$')
    shares = PosInteger()
    price = PosFloat()

class Point(Structure):
    x = Integer()
    y = Integer()

class Address(Structure):
    hostname = String()
    port = Integer()
```


Solution: XML

```
<structures>
  <structure name="Stock">
    <field type="SizedRegexString" maxlen="8"
pat="'[A-Z]+$'">name</field>
    <field type="PosInteger">shares</field>
    <field type="PosFloat">price</field>
  </structure>
  <structure name="Point">
    <field type="Integer">x</field>
    <field type="Integer">y</field>
  </structure>
  <structure name="Address">
    <field type="String">hostname</field>
    <field type="Integer">port</field>
  </structure>
</structures>
```

Solution: XML

```
<structures>
  <structure name="Stock">
    <field type="SizedRegexString" maxlen="8"
pat="'[A-Z]+$'">name</field>
    <field type="PosInteger">shares</field>
    <fie                  >price</field>
  </stru
  <struc
    <fie                  x</field>
    <field type="Integer">y</field>
  </structure>
  <structure name="Address">
    <field type="String">hostname</field>
    <field type="Integer">port</field>
  </structure>
</structures>
```

+5 extra credit
Regex + XML

XML to Classes

- XML Parsing

```
from xml.etree.ElementTree import parse

def _xml_to_code(filename):
    doc = parse(filename)
    code = 'import typestruct as _ts\n'
    for st in doc.findall('structure'):
        code += _xml_struct_code(st)
    return code
```

- Continued...

XML to Classes

```
def _xml_struct_code(st):
    stname = st.get('name')
    code = 'class %s(_ts.Structure):\n' % stname
    for field in st.findall('field'):
        name = field.text.strip()
        dtype = '_ts.' + field.get('type')
        kwargs = ', '.join('%s=%s' % (key, val)
                           for key, val in field.items()
                           if key != 'type')
        code += '    %s = %s(%s)\n' % \
                (name, dtype, kwargs)
    return code
```


Example

```
>>> code = _xml_to_code('data.xml')
>>> print(code)
import typestruct as _ts
class Stock(_ts.Structure):
   name = _ts.SizedRegexString(maxlen=8, pat='[A-Z]+
   shares = _ts.PosInteger()
   price = _ts.PosFloat()
class Point(_ts.Structure):
   x = _ts.Integer()
   y = _ts.Integer()
class Address(_ts.Structure):
   hostname = _ts.String()
   port = _ts.Integer()

>>>
```

$$!!@!&!**!!!

- Now WHAT!?!?
- Allow structure .xml files to be imported
- Using the import statement
- Yes!

Import Hooks

- sys.meta_path

```
>>> import sys
>>> sys.meta_path
[<class '_frozen_importlib.BuiltinImporter'>,
 <class '_frozen_importlib.FrozenImporter'>,
 <class '_frozen_importlib.PathFinder'>]
>>>
```

- A collection of importer/finder instances

An Experiment

```
class MyImporter:
    def find_module(self, fullname, path=None):
        print('*** Looking for', fullname)
        return None

>>> sys.meta_path.append(MyImporter())
>>> import foo
*** Looking for foo
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ImportError: No module named 'foo'
>>>
```

- Yes, you've plugged into the import statement

Structure Importer

```
class StructImporter:
    def __init__(self, path):
        self._path = path

    def find_module(self, fullname, path=None):
        name = fullname.rpartition('.')[-1]
        if path is None:
            path = self._path
        for dn in path:
            filename = os.path.join(dn, name+'.xml')
            if os.path.exists(filename):
                return StructXmlLoader(filename)
        return None
```

Structure Importer

```
class StructImporter:
    def __init__(self, path):
        self._path = path

    def find_module(self, fullname, path=None):
        name = fullname.rpartition('.')[-1]
                       ath

                       path.join(
            if os.path.exists(filename):
                return StructXmlLoader(filename)
        return None
```

Fully qualified module name

Package path (if any)

Structure Importer

```
class StructImporter:
    def __init__(self, path):
        self._path = path

    def find_module(self, fu
        name = fullname.rpar
        if path is None:
            path = self._pat
        for dn in path:
            filename = os.path.join(dn, name+'.xml')
            if os.path.exists(filename):
                return StructXmlLoader(filename)
        return None
```

Walk path, check for existence of .xml file and return a loader

XML Module Loader

```
import imp
class StructXMLLoader:
    def __init__(self, filename):
        self._filename = filename

    def load_module(self, fullname):
        mod = sys.modules.setdefault(fullname,
                          imp.new_module(fullname))
        mod.__file__ = self._filename
        mod.__loader__ = self
        code = _xml_to_code(self._filename)
        exec(code, mod.__dict__, mod.__dict__)
        return mod
```


XML Module Loader

```
import imp
class StructXMLLoader:
    def __init__(self, filename):
        self._filename = filename

    def load_module(self, fullname):
        mod = sys.modules.setdefault(fullname,
                          imp.new_module(fullname))
        mod.__file__ = self._filename
        mod.__loader__ = self
        code = _xml_to_code(self._filename)
        exec(code, mod.__dict__, mod.__dict__)
        return mod
```

Create a new module and put in sys.modules

XML Module Loader

```
import imp
class StructXMLLoader:
    def __init__(self, filename):
        self._filename = filename

                          ullname):
                          etdefault(fullname,
                          ew_module(fullname))
                          f._filename
        mod.__loader__ = self
        code = _xml_to_code(self._filename)
        exec(code, mod.__dict__, mod.__dict__)
        return mod
```

Convert XML to code and exec() resulting source

Installation and Use

- Add to sys.meta_path

```
def install_importer(path=sys.path):
    sys.meta_path.append(StructImporter(path))

install_importer()
```

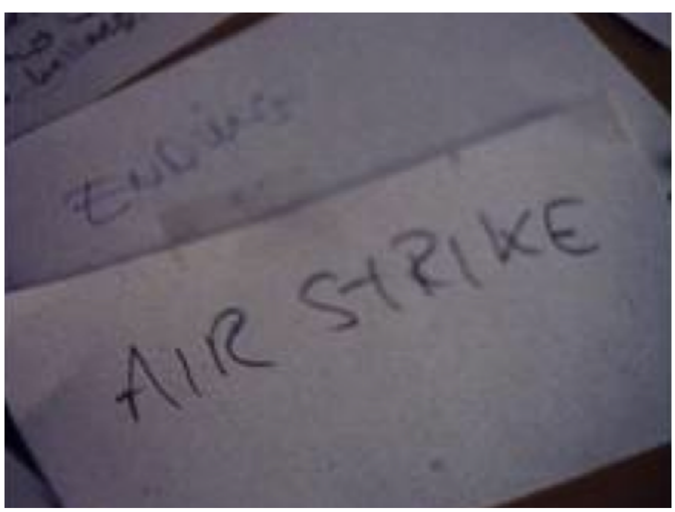
- From this point, structure .xml files will import

```
>>> import datadefs
>>> s = datadefs.Stock('ACME', 50, 91.1)
>>> s.name
'ACME'
>>> datadefs
<module 'datadefs' from './datadefs.xml'>
>>>
```

Look at the Source

```
>>> datadefs
<module 'datadefs' from './datadefs.xml'>
>>>
>>> import inspect
>>> print(inspect.getsource(datadefs))
<structures>
  <structure name="Stock">
    <field type="SizedRegexString" maxlen="8" pat="'[.
$'">name</field>
    <field type="PosInteger">shares</field>
    <field type="PosFloat">price</field>
  </structure>
...
```


Final Thoughts



(probably best to start packing up)

Extreme Power

- Think about all of the neat things we did

```
class Stock(Structure):
    name = SizedRegexString(maxlen=8, pat='[A-Z]+$')
    shares = PosInteger()
    price = PosFloat()
```

- Descriptors as building blocks
- Hiding of annoying details (signatures, etc.)
- Dynamic code generation
- Even customizing import

Hack or by Design?

- Python 3 is designed to do this sort of stuff
    - More advanced metaclasses (e.g., __prepare__)
    - Signatures
    - Import hooks
    - Keyword-only args
- Observe: I didn't do any mind-twisting "hacks" to work around a language limitation.

Python 3 FTW!

- Python 3 makes a lot of little things easier
- Example : Python 2 keyword-only args

```
def __init__(self, *args, **kwargs):
    self.maxlen = kwargs.pop('maxlen')
    ...
```

- In Python 3

```
def __init__(self, *args, maxlen, **kwargs):
    self.maxlen = maxlen
    ...
```

- There are a lot of little things like this

Just the Start

- We've only scratched the surface
- Function annotations

```
def add(x:int, y:int) -> int:
    return x + y
```

- Non-local variables

```
def outer():
    x = 0
    def inner():
        nonlocal x
        x = newvalue
    ...
```

Just the Start

- Context managers

```
with m:
    ...
```

- Frame-hacks

```
import sys
f = sys._getframe(1)
```

- Parsing/AST-manipulation

```
import ast
```


You Can, But Should You?

- Metaprogramming is not for "normal" coding
- Frameworks/libraries are a different story
- If using a framework, you may be using this features without knowing it
- You can do a lot of cool stuff
- OTOH: Keeping it simple is not a bad strategy

That is All!

- Thanks for listening
- Hope you learned a few new things
- Buy the "Python Cookbook, 3rd Ed." (O'Reilly)
- Twitter: @dabeaz